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SYSTEMATIC REVIEW Open Access

Systematic review of effects on biodiversity from oil palm production

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Abstract

Background: During the past decade there has been a growing interest in bioenergy, driven by concerns about global climate change, growing energy demand, and depleting fossil fuel reserves. The predicted rise in biofuel demand makes it important to understand the potential consequences of expanding biofuel cultivation.
A systematic review was conducted on the biodiversity impacts of three first-generation biofuel crops (oil palm, soybean, and jatropha) in the tropics. The study focused on the impacts on species richness, abundance (total number of individuals or occurrences), community composition, and ecosystem functions related to species richness and community composition.

Methods: Literature was searched using an a *priori* protocol. Owing to a lack of available studies of biodiversity impacts from soybean and jatropha that met the inclusion criteria set out in the systematic review protocol, all analyses focused on oil palm. The impacts of oil palm cultivation on species richness, abundance, and community similarity were summarized quantitatively; other results were summarized narratively.

Results: The searches returned 9143 articles after duplicate removal of which 25 met the published inclusion criteria and were therefore accepted for the final review. Twenty of them had been conducted in Malaysia and two thirds were on arthropods.
Overall, oil palm plantations had reduced species richness compared with primary and secondary forests, and the composition of species assemblages changed significantly after forest conversion to oil palm plantation. Abundance showed species-specific responses and hence, the overall abundance was not significantly different between plantations and forest areas. Only one study reported how different production systems (smallholdings vs. industrial estates) affect biodiversity. No studies that examined the effects on ecosystem functions of reduced species richness or changes in community composition met the inclusion criteria. Neither were there studies that reported how areas managed under different standards (e.g. different certification systems) affect biodiversity and ecosystem function.

Conclusions: Our review suggests that oil palm plantations have reduced species richness compared with primary and secondary forests, and the composition of species assemblage changes significantly after forest conversion to oil palm plantation. Effects of different production systems on biodiversity and ecosystem function are clear knowledge gaps that should be addressed in future research.

Trial registration: CEE10-013

Keywords: Land use change, Mitigation, Oil palm, Species diversity, Tropical forest

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Background

Over the last decade there has been a growing interest in bioenergy, especially biofuels, that has been driven by concerns about global climate change, increasing energy demand, reducing dependence on fossil fuel [1]. Energy derived from plant material, such as sugarcane and oil palm, offers, at least in theory, a promising way to answer energy demand without increasing greenhouse gas (GHG) emissions. In addition, biofuel production can create additional income for the rural poor and advance economic development [2].

Nevertheless, biofuel based opportunities do not come without concerns. Direct or indirect land use change resulting from expansion of biofuel cultivation can cause deforestation and destroy natural habitats [3,4], which in turn may lead to the loss of biodiversity [5,6]. Reduced biodiversity may have further negative impacts on ecosystem functions [7].

To respond to the concerns about potential negative social and environmental impacts, several voluntary standards have emerged since the beginning of the millennium. The most prominent have emerged from the Roundtable on Sustainable Palm Oil (RSPO) [8], which was formally established in 2004, the Roundtable on Responsible Soy Association (RRSA) in 2006 [9], and the Roundtable on Sustainable Biofuels (RSB) [10] in 2007. There have also been legislative efforts (e.g. Directive 2009/28/EC of the European Parliament and of the Council) to ensure that the production of imported is considered sustainable. However, there have been concerns that the standards are not effective enough to reduce the threat biofuel production poses to tropical forest ecosystems [11].

Currently palm oil and soybean are produced mainly for food, and thus cultivation for biofuel production has contributed little to the land-use change patterns for these crops [1,6]. Nevertheless, biofuel production has been predicted to grow [12] and it is important to know what the potential consequences of expanding biofuel cultivation are for biodiversity and biodiversity-related ecosystem functions, and to understand how well the standards in their current form might help to mitigate those impacts.

Objective of the review

The purpose of this review was to assess objectively the current state of knowledge of the impact of three first-generation biofuel crops (oil palm, soybean, and jatropha) on biodiversity in the tropics. The focus was on the direct impacts of forest conversion for crop plantations (resulting in forest fragmentation and deforestation) on species richness, abundance (i.e. overall number of individuals or occurrences) and community composition, and on ecosystem functions related to biodiversity (such as pollination, seed dispersal, biocontrol, nutrient cycling, soil fertility, decomposition). In addition to impacts, different standards related to oil palm, jatropha, and soybean were assessed for their potential to mitigate the impacts. The specific study questions were:

– Does cultivation of oil palm, soybean, and jatropha in the tropics lead to the loss of biodiversity and ecosystem functions due to deforestation and fragmentation?
– Is there a difference in the impacts on biodiversity between industrial plantations and smallholder plantations per volume of fuel produced?
– Do different standards related to oil palm, jatropha and soybean mitigate the negative impacts?

Methods

Search strategy

Design of review

An *a priori* protocol was established, peer reviewed and posted on the website of the Collaboration for Environmental Evidence (CEE) after acceptance by CEE [13]. The protocol was followed with one change: the secondary study question on standards was revised after publication of the protocol and is presented in this review in the form used.

Search sources

The original literature search was conducted between May and November 2011 and updated between October and November 2012 to retrieve articles published after November 2011. The search included academic literature databases, internet search engines, as well as websites of specialist organizations. In addition, bibliographies of articles included in the review and previously published reviews were checked for references. The following is the full list of sources searched:

Literature databases
- Biofuels abstracts database by CAB
- Directory of Open Access Journals
- Web of Science

Internet search engines
- Google: www.google.com
- Google Scholar: www.scholar.google.com
- Scirus: www.scirus.com

Websites of specialist organizations
- European Biofuels Technology Platform: www.biofuelstp.eu,
- Center for International Forestry Research: www.cifor.org
- Food and Agriculture Organization of the United Nations: www.fao.org
- Forest Trends: www.forest-trends.org
- Global Bioenergy Partnership: www.globalbioenergy.org

- The International Fund for Agricultural Development: www.ifad.org
- International Finance Corporation: www.ifc.org
- International Food Policy Research Institute: www.ifpri.org
- International Institute for Environment and Development: www.iied.org
- International Union for Conservation of Nature: www.iucn.org
- WWF: www.panda.org
- Rainforest Alliance: www.rainforest-alliance.org
- Rights and Resources Initiative: www.rightsandresources.org
- Roundtable on Sustainable Palm Oil: www.rspo.org
- Tropenbos International: www.tropenbos.org
- United Nations Framework Convention on Climate Change: www.unfccc.int
- World Resources Institute: www.wri.org

The internet search engines typically returned several thousand results. Therefore, the searches were restricted to the first fifty hits and links to potentially relevant material were followed only once from the original hit. At the websites of specialist organizations, the search was limited to the publications section of the website if there was one. At the website of the European Biofuels Technology Platform the search was restricted to sustainability articles.

Search terms and languages

Search strings were created using three categories (exposure, location, and outcome) with Boolean operators AND between categories and OR within categories (Table 1). No specific search terms were used for the study population, i.e. faunal and floral species, as they are inherent in the outcome category. A wildcard character, i.e. the asterisk, was used in the location category to include alternative word endings. When the search string could not be used in its complete form, combinations of the search terms were used so that one term from each three categories was included, e.g. oil palm AND tropic* AND species richness. Owing to the limitations of the search engine, two search strings were used for the Directory of Open Access Journals: *(Oil palm OR jatropha OR soybean) AND tropic** and *(Oil palm OR jatropha OR soybean) AND tropical*. Similarly, only terms *Oil palm OR jatropha OR soybean* were used at the website of Forest Trends –organization owing to the limitation on number of words imposed by the search engine. The search terms were also translated into French, Spanish, German, Swedish, and Finnish (Additional file 1) and searches conducted using the same logic.

Table 1 Search terms in different categories

Exposure	Location	Outcome
Oil palm		Species diversity
Soybean	Tropic*	Species richness
Jatropha		Species abundance
		Species similarity
		Species composition
		Community composition
		Deforestation
		Land use change
		Fragmentation
		Habitat loss
		Connectivity
		Functional diversity
		Ecosystem
		Displacement

*Denotes a wildcard character that was used to include alternative word endings.

Study inclusion criteria

In collaboration with stakeholders, a set of inclusion criteria was developed. Studies that had data about relevant subject, exposure and outcome, together with a valid comparator were included if they fulfilled the quality criteria discussed in the section on study quality assessment.

Studies related to the primary study question were included according to the following criteria:

- Geographical location: Study area within the tropics (23.438°S to 23.438°N).
- Relevant subject(s): Faunal and floral species.
- Type of exposure: Conversion of the land to cultivate oil palm, soybean, and jatropha for any purpose.
- Type of comparator: Other land use or land cover (primary forest, logged-over forest, secondary forest (*i.e.* regrowth forest), scrubland, grassland, cropland). Both before-after and site comparison studies were accepted.
- Types of outcome: Change in species richness, abundance (the overall number of individuals or occurrences), community composition, and ecosystem functions (pollination, seed dispersal, biocontrol, soil processes).
- Types of study: Qualitative and quantitative primary studies as well as descriptive studies and reports.

For the secondary study question “Is there a difference in the impact on biodiversity between industrial plantations and smallholder plantations per volume of fuel produced?”, location, subjects and outcome were the same, but the types of exposure and comparator were different:

- Type of exposure: Conversion of the land to industrial plantations for the cultivation of biofuel crops
- Type of comparator: Smallholder plantations

For the secondary study question "Do different standards related to oil palm, jatropha, and soybean mitigate the negative impacts?" the following criteria were used:

- Relevant subject(s): Faunal and floral species.
- Types of exposure: Standard in place should mitigate the impact of crop cultivation on biodiversity.
- Types of comparator: Standards were compared against each other to clarify how they mitigate the impact on biodiversity.
- Types of outcome: Any reported change within and nearby production area.
- Types of study: Standards related to oil palm, jatropha, and soybean, *i.e.* international legislation, industry standards, ISO management standards, NGO standards

Articles were assessed for relevance first by title, as well as keywords if these were available, then by abstract, and finally, by full text. If the inclusion of an article was in doubt in either of the first two stages, the article was included and the suitability determined at a later stage.

To assess the consistency in the use of inclusion criteria a kappa test was performed. Two reviewers applied the inclusion criteria to a random set of 108 articles at the abstract filter stage. The kappa statistic was calculated to measure the level of agreement between the reviewers. A score of 0.704 was achieved, which indicates substantial strength of agreement [14].

Potential effect modifiers and study quality assessment

Studies do not happen in a vacuum and hence, a number of variables that have the potential to affect study outcomes were recorded when available. The focus was on variables that can influence reliability and generalization of the findings. The following variables were recorded:

- Temporal and spatial scale. The temporal and spatial aspects of sampling were recorded, as well as whether sampling effort was evaluated.
- Comparator features: before/after or site comparison.
- Methodology used to collect data.
- Environmental features of the site: soil type, original vegetation, and the type of surrounding landscape
- Variables related ecological interactions: competition and predation.
- Variables related to plantation management: use of herbicides, insecticides, and fertilizers.
- Plantation type (industrial vs. smallholder), age, size, and certification status.

To avoid misleading conclusions by including studies with inappropriate design, the studies were evaluated according to the hierarchy of quality of evidence (Table 2). Studies that fell into the category VI were excluded from analysis.

Data extraction and synthesis

Originally we planned to categorize the data for the analyses using the following five categories: Mammals, birds, amphibians and reptiles, invertebrates, and plants. However, as there were relatively few studies overall, the data were not categorized in this way for the analysis.

There were enough data on species richness (i.e. number of species) and abundance (i.e. overall number of individuals or occurrences) to perform meta-analysis. The purpose of meta-analysis is to quantitatively summarize the results of individual studies using specific statistical methods [16]. The concept at the heart of a meta-analysis is the effect size, which is a statistical measure that portrays the magnitude of which given effect is present in a sample. It makes it possible to determine whether the overall effect is greater than expected by chance [17]. There are several effect size estimates that measure the standardized mean difference between two samples and are thus suitable for species richness and abundance data. Hedges' d was chosen because it corrects for a small sample size [18] (for the equations used in this section see the Additional file 2). The heterogeneity of the effect sizes was estimated using the Q-statistic. The I^2-statistic was used to describe the proportion of the observed variance that reflects real differences in effect sizes [19].

Table 2 Hierarchy of quality of evidence based on the information provided in the documents

Category	Quality of evidence presented
I.	Randomized controlled trials of adequate spatial and temporal scale for the study species.
II.	Controlled trials without randomization with adequate spatial and temporal scale for the study species.
III.	Comparisons of differences between sites with and without controls with adequate spatial and temporal scale for the study species.
IV.	Evidence obtained from multiple time series or from dramatic results in uncontrolled experiments.
V.	Opinions of respected authorities based on qualitative field evidence, descriptive studies or reports of expert committees.
VI.	Evidence inadequate owing to problems of methodology e.g. sample size, spatial or temporal scale.

Modified after [15].

To perform a quantitative meta-analysis on species richness and abundance the estimates of mean species richness and abundance, the corresponding estimates of standard deviations, and sample sizes were tabulated. If the estimate of standard deviation was not provided it was calculated from the estimate of standard error and sample size. In some cases the estimates of mean and standard deviation or standard error were measured from the published figures. The measurements were made by one person, so any measurement error is expected to be consistent. In cases where the estimates of mean and standard deviation were not provided but a *t*-statistic was, this was used to calculate Hedges' *d* by transforming the *t*-statistic first to Hedges' *g* and the *g* then to Hedges' *d* [18].

The effect sizes were analyzed using a random effects model. This was chosen because the subject groups and data collection methods varied between the studies and hence, there may be real differences among effect sizes of studies on different subjects [19,20]. Different taxa and taxa that were collected using different methods within the same study were treated as independent samples. Also, data that had significant differences between sampling occasions [21,22] were included as independent samples. Studies by different authors from the same location, regardless of the taxa studied, were treated as separate cases. Although originally we wanted to include explanatory variables into the model, this was not feasible owing to the small number of studies that met the inclusion criteria and hence, only the average effect sizes were estimated, along with 95% bias-corrected confidence intervals. The bias-corrected confidence intervals were chosen because of the relatively small sample sizes. The analyses were performed using MetaWin 2.1 release 5.10 [23].

One of the well-known problems associated with meta-analysis is that studies with higher effects are more likely to be published; relying only on results published in academic journals can potentially lead to misleading conclusions about the effect [19]. To address this problem, an extensive search was performed to uncover "grey" (variously defined, but here we mean conference papers, book chapters, reports that are no part of established Series, etc.) and unpublished literature. Another reported source of publication bias is that non-significant results may not be published at all. We did not test for publication bias for two reasons. First, a variety of responses are expected in ecological studies dealing with different taxa and we therefore did not expect suppression by Editors of studies of smaller effects or non-significant results. Secondly, existing statistical tests require reasonable numbers of cases and dispersion in sample sizes, two conditions which the meta-analyses we performed do not fully meet.

A variety of different methods used for examining changes in species composition makes it difficult quantitatively to assess the effects of habitat modification on species composition. Hence, to have a standardized measure to assess changes in species composition, a simple averaging method following Nichols *et al.* [24] was used to calculate the mean change in the number of shared species between forest and oil palm habitats, standardized by the total number of species recorded in forest. In addition to the mean response, 95% confidence intervals were calculated. The value was considered significant when the confidence interval did not include one. Primary and secondary forest data were combined in the analysis. When both primary and secondary forests were sampled, only primary forest data were used. The analysis was performed using SPSS version 17.0 [25].

Results

Review statistics

The searches returned 9143 articles after duplicate removal (Figure 1). Of these articles, approximately 13 per cent had a relevant title and keywords and were therefore examined further. At the abstract-assessment stage 9.8 per cent of articles satisfied the inclusion criteria and were read in full. Of those, 25 articles (21 per cent of those read in full) reported single studies with an appropriate comparator (Additional file 3). All of the selected studies belonged to category III (Table 2), which meant that none were excluded on the grounds of weak methodology.

Description of studies

Source

All 25 articles included in the review were published in peer-reviewed journals. Only three articles were published before 2000, and the majority of the articles were published after 2005 (Figure 2). The figure for 2012 is not fully representative of the whole year because the search was conducted on articles published by the bibliographic databases up to November 2012.

Context of the studies

Study location Most of the studies were conducted in Asia: 20 of them in Malaysia. Of the studies conducted in Malaysia, 10 were from one State Sabah. There were only single studies from other tropical regions, Africa (Ghana), Oceania (Papua New Guinea), and Latin America (Dominican Republic).

Study comparator Only studies of oil palm were retrieved using our search strategy. Typically, oil palm plantations were compared with forest, either primary ($n = 20$) or secondary forest ($n = 14$). All except one study were site comparisons. None of the studies were experimental. Only one of the studies examined outcomes before and after forest conversion.

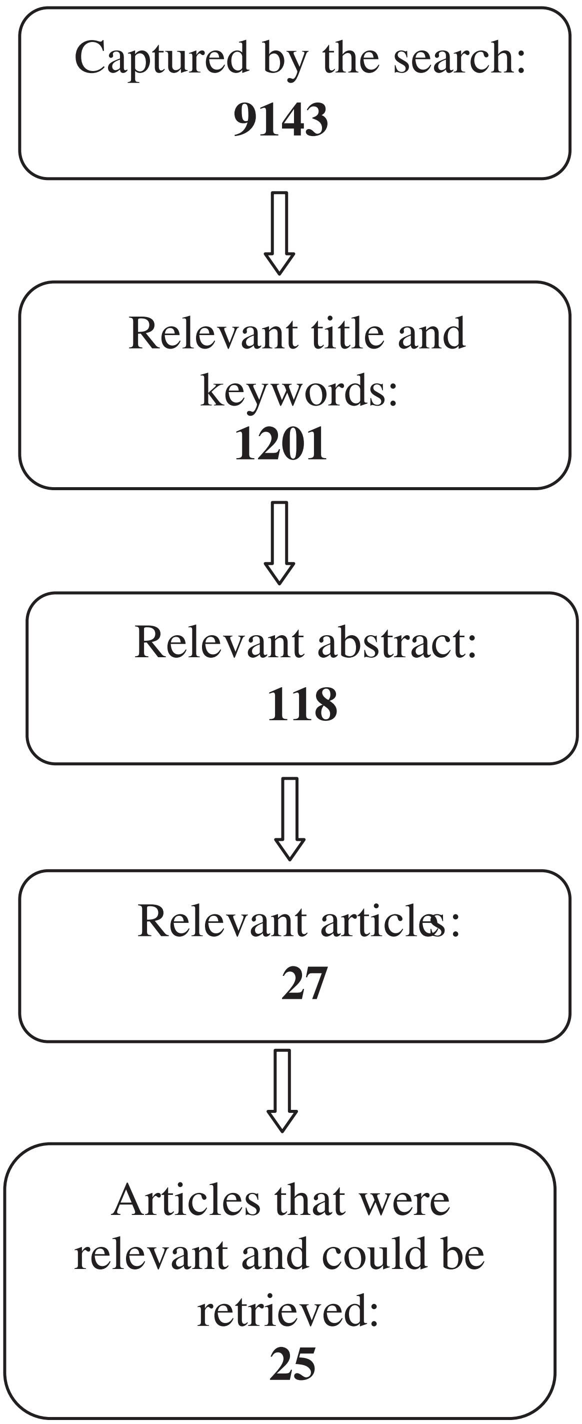

Figure 1 The number of articles at different assessment stages.

Study outcomes The 25 studies reported a total of 58 outcomes. All studies had examined faunal species richness/diversity ($n = 25$); almost all had examined abundance ($n = 21$), but only 12 had looked at species composition. Almost two thirds of them studied invertebrates (Figure 3).

The age and size of the plantations The age of the plantations was reported in 15 studies; two additional studies mentioned that the plantation was 'mature'. The age of the plantations varied from one year to more than 25 years. Nine studies collected data from plantations aged less than ten years, eight studies collected data from plantations aged ten years or more, including the study by Azhar *et al.* [26] that collected data from oil palm plantations of varying ages. Only ten studies mentioned plantation area, which ranged from 36 to 16000 hectares, with the majority of studies having studied plantations of several thousand hectares (Figure 4).

Study designs and methodology

All studies included in the review used quantitative methods. All except one study were site comparisons between oil palm plantation and primary or secondary forest or both. In the one before-and-after study Chang *et al.* [27] studied changes in abundance of mosquitoes induced by land use change during the development of an oil palm plantation.

All site comparison studies selected sites that could be paired and, except for Koh and Wilcove [28], collected data from the sites during same time period. Koh and Wilcove [28] used butterfly data collected from primary and logged forest in two earlier studies [29,30] and compared with the data they collected from an oil palm plantation. The exact method for site selection or pairing was described in only four studies [26,31-33]. It was impossible to assess the robustness of the selection in the other studies. Similarly, the selection of sub-sites within the studied habitats was unclear in most of the studies as even the studies that selected sub-sites randomly did not explain the exact method for randomization.

Half of the studies reported distance between the sites and only ten studies discussed leakage effects from or to adjacent areas. One of these [32] was specifically focused on spillover of butterflies and ants from forest to oil palm plantations and found that although vagrant forest butterflies were found in the plantations, recapture data did not reveal dispersal of butterflies across the forest-plantation ecotone. No spillover of ant species was reported. In addition, it was reported that leakage from adjacent areas was unlikely owing to behavioral characteristics [34] to dispersal capabilities [27,35] or ecological conditions [36]. In three studies on birds it was reported that nearby primary forest areas either 'probably' [37] or 'certainly' [26,38] contributed to the species richness in oil palm landscapes. Similarly, Gillespie *et al.* [39] suggested that it is possible that the occurrence of arboreal amphibian species (tree frogs), specifically *Rhacophorus appendiculatus, Rhacophorus dulitensis and Rhacophorus pardalis*, in the plantation resulted from local dispersal from nearby forest habitats. Juliani *et al.* [40] suspected that the lack of

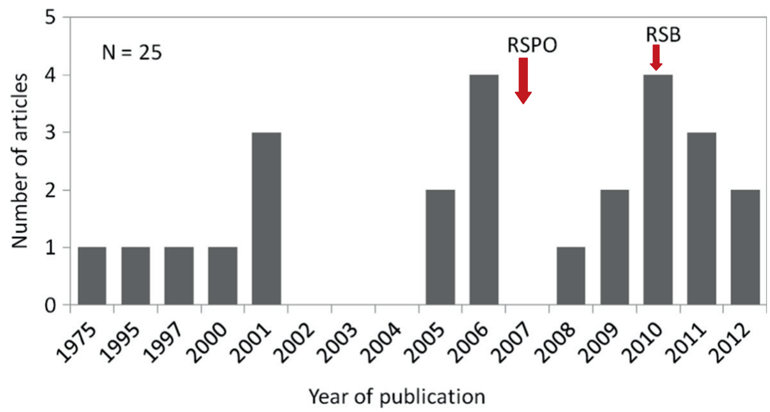

Figure 2 Number of articles published in different years. The articles shown are limited to those included in this systematic review. For articles published before 2000 only those years in which an article was published are shown. Arrows indicate the years when standards from Roundtable on Sustainable Palm Oil (RSPO) and Roundtable on Sustainable Biofuels (RSB) were first published.

shelter or roosting sites in areas adjacent to the oil palm plantation studied could have contributed to the high abundance of bats in the plantation.

The species studied in the faunal studies varied considerably, and therefore the data collection methods also differed (Table 3). Sampling effort was statistically evaluated in almost two thirds of the studies (58%) and in addition one more study [41] reported that it was 'low'. The most frequently reported method of evaluating sampling effort was by use of species accumulation curves; comparisons between observed and predicted species richness were used in three studies [22,26,36]. Generally, the studies that had statistically evaluated the sampling effort deemed it to be satisfactory to show the differences (or lack of differences) between the sites, and 11 of the 14 studies specifically discussed that point.

Nine of the studies explicitly reported efforts aimed at minimizing or controlling for the effect of extrinsic variables. For example, sampling at the same time of the day, or only in fine weather conditions, collecting samples away from the edges of the habitat, and sampling birds at a limited spatial scale to ensure visibility.

Temporal and spatial scale of the studies

Temporal and spatial scales are important in several contexts. Although the spatial scale of data collection can influence the results of faunal studies [51], this was rarely discussed in the studies. Only two studies [32,35] discussed the results in the context of spatial scale, specifically in relation to the dispersal abilities of the species in question.

None of the studies collected long-term data and hence, the studies are based on a rather limited time scale. In addition, only two studies assessed the effects of seasonality. Fukuda *et al.* [48] conducted censuses on bats four times within 17 months and did not detect any significant differences between the seasons. Lucey and Hill [32] compared

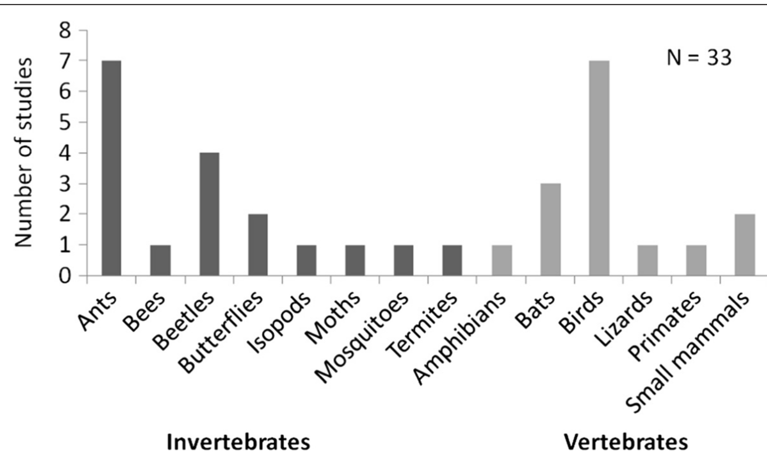

Figure 3 Taxonomic groups studied in the 25 studies on biodiversity included in the review. Some of the studies studied several taxonomic groups.

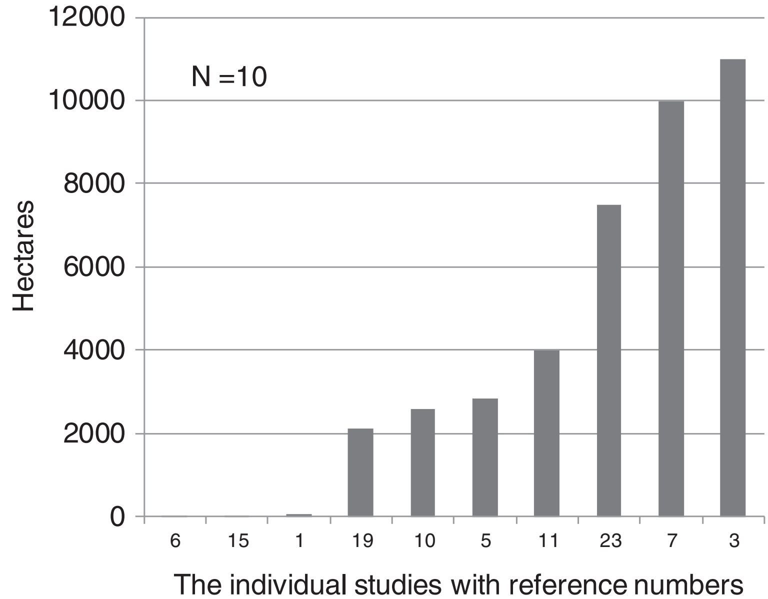

Figure 4 The size of plantations studied. The bars represent individual studies and the labels refer to the study numbers in Additional file 3.

similarity of species assemblages between first and second sampling occasion and concluded that for butterfly species temporal turnover contributed substantially to overall diversity. For ant species the similarity of species assemblages was higher for both forest and oil palm habitats and thus, temporal turnover had less impact on the diversity of ants than butterflies.

Quantitative synthesis

Species richness

We found 11 studies that provided suitable data for conducting meta-analysis to compare species richness in oil palm plantations and primary forest, and 8 whose data could be used for comparison between oil palm plantations and secondary forests. Owing to the limited amount of suitable data we focused on overall effects. Although examining only overall effects can mask differences in responses between taxa, it was done out of necessity to retain power in the analyses. As primary and secondary forests can be biologically very different environments, the analyses were done separately.

There was relatively uniform negative response as shown in the forest plots of differences in species richness between oil palm plantation and either primary or secondary forest (Figures 5 and 6). The estimated mean effect size was significantly different from zero (primary forest: E++ = -1.41, 95% bias-corrected CI -2.06 to -0.90; secondary forest: E++ = -3.02, 95% bias-corrected CI -4.42 to -1.84) indicating that oil palm plantations have fewer species than either primary or secondary forest. As the effect sizes got larger, the confidence intervals were also wider.

There was heterogeneity in the effects when the species richness of plantation was compared to that of primary forest ($Q = 29.76$, $p = 0.02$), but not when the comparison was between plantation and secondary forest ($Q = 16.19$, $p = 0.24$). The I^2 index indicated that 43% of the variance considering the effects regarding plantations and primary forests reflects real differences in the effect sizes. Correlations between effect and sample sizes were not significant (Spearman's rank correlation, $p > 0.05$) for either primary or secondary forest implying that larger effects in one direction were not reported more often than other effects, but at low samples sizes the power of the correlation is rather low [19].

Abundance

There was more dispersion in the direction of effect sizes of abundances (i.e. the overall number of individuals or occurrences) than of species richness and the mean effect size was not significantly different from zero for the comparison of an oil palm plantation to either primary forest (E++ = -0.92, 95% bias-corrected CI -2.03 to 0.01) (Figure 7) or secondary forest (E++ = -0.21, 95% bias-corrected CI -1.58 to 0.75) (Figure 8). However, it is important to note that the results for the secondary forests were based on only four independent studies, and that owing to the limitations in data available, we aggregated all taxa in these analyses. As with species richness, larger effect sizes had larger confidence intervals.

There was heterogeneity in the effect sizes when the abundance of plantations was compared with primary forest ($Q = 31.88$, $p = 0.02$) as well as with a secondary forest ($Q = 19.35$, $p = 0.01$). The I^2 index indicated that

Table 3 Summary of methods used in the studies included in the review

Study	Taxonomic group	Collected data	Sampling method	Methodology
Invertebrates				
Brühl & Eltz [36]	Ground-dwelling ants	Species richness	Tuna baits	Baits along 105 transects of various lengths (10-100 m)
Chey [31]	Moths	Species richness, abundance and composition	Light traps	One light-trap at each site for 3 consecutive nights.
Chang et al. [27]	Mosquitoes	Species richness and abundance	Human baits	All-night human landing collections on 5 consecutive nights each year.
Chung et al. [21]	Subterranean beetles	Species richness, abundance and composition	Winkler sampling	Ten 1 m^2 samples of leaf litter and soil at each site.
	Understorey beetles	Species richness, abundance and composition	Flight-interception-trapping	3 traps per site. Two weeks of sampling. Only samples from alternate days used.
	Arboreal beetles	Species richness, abundance and composition	Mist-blowing	10 trees at least 10 m apart
Davis & Philips [22]	Dung beetles	Species richness and abundance	Pitfall traps	4 sites per habitat, 3 traps per site at least 10 m apart, two 24-hour periods
Fayle et al. [42]	Canopy ants	Species richness, abundance and composition	Fogging	20 transects per habitat
	Ants in the ferns	Species richness, abundance and composition	Entire ferns collected, litter and core fragments processed.	20 transects per habitat
	Leaf litter ants	Species richness, abundance and composition	Litter samples	20 transects per habitat
Hashim et al. [41]	Ants	Species richness	Hand-collecting and pitfall traps	3 randomly-distributed 0.25 m^2 subplots within each of three 10 m × 10 m plots and 5 pitfall traps per habitat.
Hassall et al. [35]	Terrestrial isopods	Species richness and abundance	Quadrats	Plots sampled on a stratified random basis.
Koh & Wilcove [28]	Butterflies	Species richness	Banana-baited traps	98 trapping sites with total of 48 hours of trapping
Liow et al. [43]	Bees	Species richness, abundance and composition	Honey-baited traps in transects	Non-randomly selected 1-3 transects per site. On average 12.85 hours surveyed per transect
Lucey & Hill [32]	Ground-dwelling ants	Species richness, abundance, and composition	Pitfall traps	2000 m transects, f1ve traps per trap station, six trap stations in forest and in oil palm plantations, 100 m between trap stations. Sampled twice for 12 consecutive days.
	Butterflies	Species richness, abundance, and composition	Fruit-bated traps	Two 2000 m transects, 10 trap stations in forest and in oil palm plantation, 100 m between trap stations. Sampled twice for 12 consecutive days at both occasions.
Room [44]	Ground foraging ants	Species richness, abundance and composition	Quadrats	30 samples per habitat.
Vaessen et al. [33]	Termites	Species richness, abundance and composition	Transects	One transect established randomly at each site.

Table 3 Summary of methods used in the studies included in the review *(Continued)*

Vertebrates				
Aratrakorn et al. [45]	Birds	Species richness and relative abundance	Timed Species Counts	30 oil palm plantations selected from aerial photographs. The number of sites based on preliminary counts. Two counts of 20 min divided into five 4-minute blocks.
Azhar et al. [26]	Birds	Species richness, abundance and composition	Transect counts	470 various-length transects: 418 in plantation estates, 52 in smallholdings and 20 in peat swamp forest.
Bernard et al. [34]	Non-volant small mammals	Species richness, abundance and composition	Live cage traps with baits	50 traps per trapping site arranged into 5 200 m long trap lines.
Danielsen & Heegaard [46]	Birds, primates, tree-shrews, and squirrels	Species richness, abundance, and composition	Variable-distance line-transect	2000 m straight line; surveyed for 40 hours in forest areas and for 20 hours in oil palm.
	Bats	Species richness, abundance, and composition	Mist nets	15-20 nets (totaling 150-250 m).
Edwards et al. [47]	Birds	Species richness and abundance	Timed point-counts along transects	5 sites per habitat, 12 sampling points at 250 m intervals at each site.
Fukuda et al. [48]	Bats	Species richness and abundance	Mist nets and harp traps	2-4 mist nets per night, 3-6 census points per habitat.
Gillespie et al. [39]	Amphibians	Species richness and composition	Transects	400 m transects; 6 in wet forest, 5 in dry forest, and 3 in oil palm plantation. Each sampled 3-4 times.
Glor et al. [49]	Lizards	Species richness and abundance	Glue traps	Non-randomly selected 10 x 10 m trapping grids with 20 traps each, 3 plots in oil palm, 4 in *mogote*.
Juliani [40]	Bats	Species richness and abundance	Mist nets	10 mist nets randomly placed in each habitat type.
Peh et al. [38,50]	Birds	Species richness and abundance	Point counts	240 point counts arbitrary chosen. At least 200 m from each other. 127 sites in the oil palm.
Sheldon et al. [37]	Birds	Species richness, abundance and composition	Point counts	20 three-minute point counts at 50 m intervals along the transects.

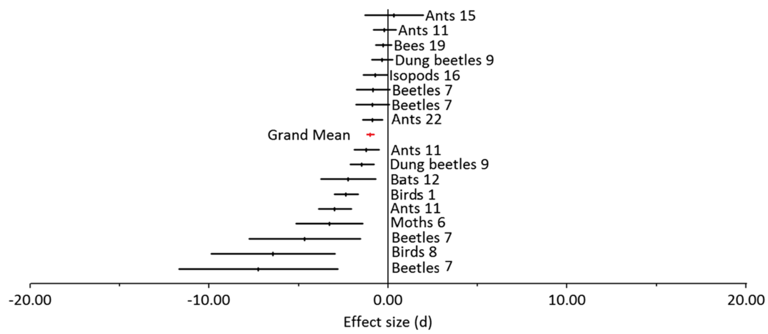

Figure 5 Forest plot of effect sizes for species richness (mean standardized difference between primary forest and oil palm plantation). The grand mean is the summary effect of all the individual effect sizes. The error bars represent 95% confidence intervals. The numbers after the taxa refer to the study number in Additional file 3.

47% of the variance considering the effects regarding plantations and primary forests reflects real differences in the effect sizes. The figure was 59% when faunal abundance of secondary forests and plantations are compared. Correlations between effect and sample sizes were not significant for either primary or secondary forest (Spearman's rank correlation, $p > 0.05$).

Species composition

The similarity of species composition was statistically assessed in 12 of the original studies while a further 11 studies provided some information about species composition (Tables 4 and 5). Species composition differed between forest and oil palm plantation areas in all except one of the 23 studies. In most of the studies that had statistically assessed the difference, the similarity between plantation and forest areas was either low or zero. However, the statistical methods used differed between the studies and results are therefore not directly comparable.

To have comparable results, a mean of shared species between oil palm plantation and forest was assessed. There were 10 studies on invertebrates and 9 studies on vertebrates that provided suitable data for the comparison. On average only 29% of the invertebrate species and 22% of the vertebrate species were shared between oil palm plantation and forest after the values were standardized (Table 6, Figure 9). This represents significant change in community composition for both invertebrates and vertebrates.

Narrative synthesis

Biodiversity in industrial versus smallholder plantations

Only one study [26] addressed differences in species richness and community composition between smallholder and industrial plantations. The results showed that, on average, smallholdings with mixed-age stands supported higher bird species richness than industrial plantation estates that had uniform age structure (range from <6 years old to >25 years old). The average dissimilarity of bird assemblages between the plantation estates and smallholdings was 47.6%. However, since yields were not taken into account in the analyses, it is not known whether the impact is similar when compared for equivalent amounts of fuel produced under different management systems.

Explanatory factors for differences in species richness and community composition

Only four studies had statistically analyzed the causes of differences in either species richness or community

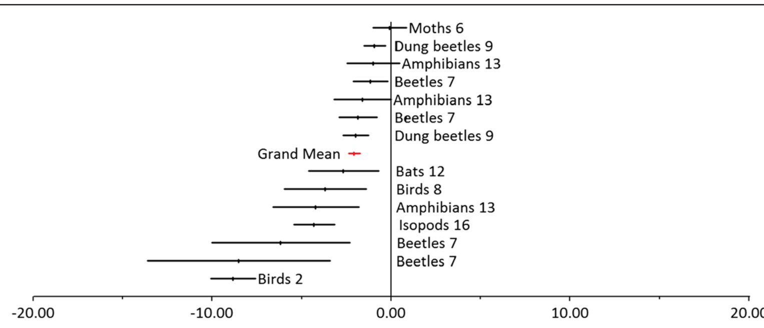

Figure 6 Forest plot of effect sizes for species richness (mean standardized difference between secondary forest and oil palm plantation). The grand mean is the summary effect of all the individual effect sizes. The error bars represent 95% confidence intervals. The numbers after the taxa refer to the study number in Additional file 3.

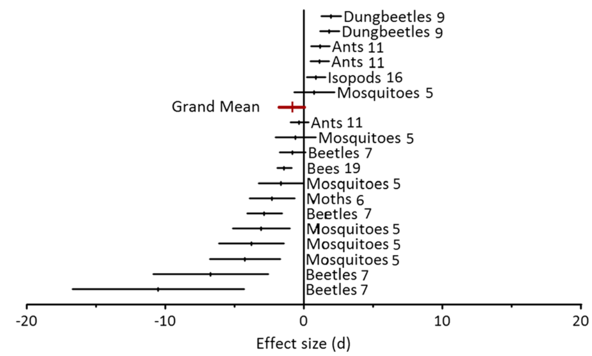

Figure 7 Forest plot of effect sizes for abundance of individuals (mean standardized difference between primary forest and oil palm plantation). The grand mean is the summary effect of all the individual effect sizes. The error bars represent 95% confidence intervals. The numbers after the taxa refer to the study number in Additional file 3.

composition. For birds, the statistical analyses showed that increased ground vegetation and undergrowth height, as well as decreased canopy cover, were all correlated with higher species richness [26]. In addition, increased proximity to a forest patch, cumulative area of natural forest patches, and decreased isolation distance positively influenced bird species richness [26]. The role of food resources was speculated about in the discussion but not tested.

In the case of invertebrates, the hotter and drier conditions in oil palm plantations were the main cause of changes in community compositions (ants [42]; beetles [21]; bees [43]). Soil pH was a significant factor for isopods [35], whereas the amount of leaf litter, tree and sapling densities, and plant species richness were significant factors for primary forest beetle species [21].

Ecosystem function

None of the studies had specifically looked at biodi versity-related ecosystem functions, such as pest control,

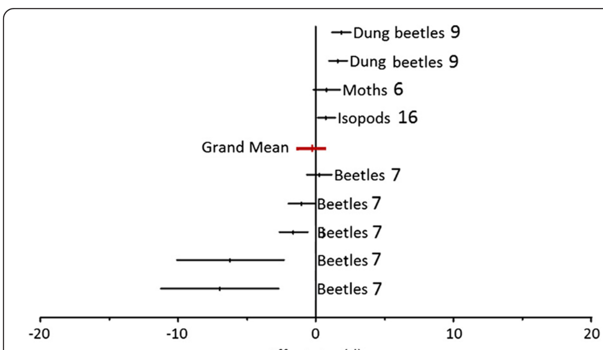

Figure 8 Forest plot of effect sizes for abundance of individuals (mean standardized difference between secondary forest and oil palm plantation). The grand mean is the summary effect of all the individual effect sizes. The error bars represent 95% confidence intervals. The numbers after the taxa refer to the study number in Additional file 3.

pollination and soil processes that might have included supporting data. However, we found some discussions about concern for the continuity of pollination processes after expansion of oil palm habitats, and the changed communities between primary forest and other areas [40,43]. In summary, these postulated that there would be negative consequences for forest regeneration if remaining forest areas cannot support large enough pollinator populations and pollinators are also absent in the surrounding oil palm matrix.

Biofuel-related standards

There were no studies that had tried to assess the impact of the standards on biodiversity. In fact, only a few of the studies reported whether the oil palm plantations studied were complying with standards. None of these had been structured to compare impacts before and after standards were applied (for a qualitative assessment of the standards see Additional file 4).

Discussion

Evidence of impact

Although the number of studies that met the inclusion criteria was small relative to the amount of literature broadly related to the review topic, the evidence on species richness and community similarity from the included studies showed clearly that oil palm plantations have reduced species richness compared with primary and secondary forests, and the composition of species assemblage changes significantly after forest conversion to oil palm plantation. Species-specific responses would be expected to vary, but based on the studies included in the review, regardless of the taxa, forest specialists do not, in general, succeed in oil palm plantations. The findings are consistent with previous reviews that have addressed similar questions [5,28,52,53].

With respect to abundance, responses appear to vary depending on species and there is no clear overall effect in one direction. When the abundance results are considered in the light of the results on species richness and similarity, it appears that certain invertebrate species, e.g. generalist species, increase in abundance after forest conversion whereas others decline. However, it is possible that the responses may differ for vertebrates, as none of the studies in the meta-analysis looked at abundance of vertebrate taxa in forest compared with plantation.

Reasons for variation in impact

The variation in effect sizes observed in the meta-analysis most likely reflects different ecological requirements of different taxa and different species within these taxa. Part of the variance in the effect sizes was due to real differences between taxa rather than general heterogeneity, but the small number of studies included in the analyses did

Table 4 Summary of information on species composition provided in the reviewed studies*

Authors	Year published	Taxonomic group	Similarity between primary forest and plantation	Similarity between secondary forest and plantation	Statistics used	Changes in communities between forest and plantation	Notes on similarity	Causes
Invertebrates								
Brühl & Eltz [36]	2010	Ground-dwelling ants	-	-	-	Yes	Communities of plantations dominated by a small number of, partly invasive, non-forest taxa. Highly impoverished in regard to forest taxa.	Absence of leaf litter. Hot and dry conditions possibly prevent colony establishment and reduce survival.
Chang et al. [27]	1997	Mosquitoes	100%	-	-	No	Lower abundances but same species composition.	na
Chey [31]	2006	Moths	0.278		Preston's coefficient of faunal resemblance	Yes	Noctuid and arctiid species dominated the assemblages.	Low floristic diversity. Lichens and other host plants. Open habitat (many noctuid and arctiid species favor open habitat).
Chey [31]	2006	Moths	0.228					
Chey [31]	2006	Moths	0.970					
Chung et al. [21]	2000	Subterra-nean, understorey and arboreal beetles	-	-	Detrended Correspondence Analysis and Canonical Correspondence Analysis	Yes	Species composition significantly different between sites (primary forest, secondary forest and oil palm). A few species dominated the assemblage at the plantation site.	**The amount of litter, tree and sapling densities, and plant species richness.**
Davis & Philips [22]	2005	Dung beetles	22.5%	-	Steinhaus similarity coefficient; Persentage disagreement distance measure; Cluster analysis and ordination	Yes	Similarity between both forest types and plantation.	Physiognomic differences.
Fayle et al. [42]	2010	Ants (canopy)	S: 0.191, C: 0.301	-	Sørenson's classic similarity index; Chao's incidence-based measure with a correction for unseen species	Yes	Only a small proportion of forest ant species were present in oil palm plantation. Non-native species were much more widespread.	**Temperature nearly significant factor (*P* = 0.073). Simplification of the canopy structure. Competitive interactions.**
Fayle et al. [42]	2010	Ants (ferns)	S: 0.056, C: 0.070	-	Sørenson's classic similarity index; Chao's incidence-based measure with a correction for unseen species	Yes	Only a small proportion of forest ant species were present in oil palm plantation. Non-native species were much more widespread.	Competitive interactions.
Fayle et al. [42]	2010	Ants (leaf-litter)	S: 0.213, C: 0.555	-	Sørenson's classic similarity index; Chao's incidence-based measure with a correction for unseen species	Yes	Only a small proportion of forest ant species were present in oil palm plantation. Non-native species were much more widespread.	**Temperature. Hotter and drier environment. Competitive interactions.**
Hashim et al. [41]	2010	Ants	-	-	-	Yes	Four species found in the plantation were absent from mangrove forest and two species found in the mangrove were absent from the plantation.	na
Hassall et al. [35]	2006	Terrestrial isopods	-	-	-	Yes		na

Table 4 Summary of information on species composition provided in the reviewed studies* *(Continued)*

Liow et al. [43]	2001	Bees	-	-	Cluster analysis and canonical correspondence analysis	Yes	Families Halictidae and Anthophoridae were more commonly caught in oil palm plantation.	**The occurence of families Halictidae and Anthophoridae were correlated with higher temperatures and light intensity, lower humidity levels and greater flowering intensities.**
Lucey & Hill [32]	2012	Ants	-	-	Non-metric multidimensional scaling	Yes	NMDS differentiated between the habitats.	Air and soil temperature.
Lucey & Hill [32]	2012	Butterflies	-	-	Non-metric multidimensional scaling	Yes	Two distinct clusters, one for forest and one for plantation.	Air and soil temperature.
Room	1975	Ground foraging ants	25.0%	-	Percentage similarity expressed as 100 × [(2 × number of occurences common to both)/(sum of occurences present in each)]	Yes	Only a small proportion of forest ant species were present in oil palm plantation. Non-native species were much more widespread.	na
Vaessen et al. [33]	2011	Termites	-	-	-	Yes	The assemblage dominated by *Schedorhinotermes*.	Decrease in the amount of dead wood.
Vertebrates								
Aratrakorn et al. [45]	2006	Birds	-	-	-	Yes	Plantations dominated by few species. 60% of the species recorded only in the forest, 3% only in the oil palm plantation. Species recorded only in the forest had significantly smaller ranges. Species that were recorded in both forest and plantations had smaller body size than species recorded only in forest.	na
Bernard et al. [34]	2009	Non-volant small mammals	12.0%	-	Proportional difference calculated following a formula by Thiollay (1992); a hierarchical cluster analysis	Yes	Both forest types (primary and secondary) combined. Oil palm plantations may act as an effective barrier to the dispersal of small mammals.	na
Danielsen & Heegaard	1995	Birds	38.7%	-	Proportional difference calculated following a formula by Thiollay (1992)	Yes	Widespread, generalist, and common species much more abundant in plantations than in the primary forest.	Plantation age, proximity to forest, microhabitat structure, and level of human disturbance.
Danielsen & Heegaard	1995	Primates	0.0%	-	Proportional difference	Yes		na
Danielsen & Heegaard	1995	Squirrels and tree-shrews	0.0%	-	Proportional difference	Yes	No squirrels or tree-shrews observed in the plantation.	na
Danielsen & Heegaard	1995	Bats	13.0%	-	Proportional difference	Yes	Insectivorous bats appear to be more susceptible to conversion than frugivores/nectarivors.	na
Edwards et al.	2010	Birds	10.0%		Analysis of Similarity	Yes		na
Fukuda et al. [48]	2009	Bats	-	-	-	Yes	Certain species absent in the oil palm plantation: Two frugivorous species were	The absent frugivorous species rarely use agricultural lands for feeding.

Table 4 Summary of information on species composition provided in the reviewed studies* *(Continued)*

							not recorded at all, only two insectivorous species recorded.	
Gillespie et al. [39]	2012	Amphibians	0.592 ($p = 0.0002$)	-	Analysis of Similarity between all forest transects and plantation and non-forest transects combined.	Yes	The assemblages reflect the strong affinities of certain species with particular habitat types. Plantation assemblages dominated by terrestrial, non-endemic, generalist species.	Absence of suitable microhabitats. The simple structure and open canopy of plantations results in greater temperature flux between day and night, increased evaporation rates and lower humidity.
Glor et al.	2001	Lizards	-	-	-	Yes		Microhabitat availability in regard to, at least, two species (grass-bush anole and Cochran's dwarf gecko). Oil palm plantation lacks the perch availability and understory microhabitat of natural forest.
Peh et al.	2005, 2006	Birds	-	-	Multiresponse permutation procedure	Yes	Forest species constituted only 26% of the total individuals observed in plantation. Nearby primary forest may act as a source habitat.	Simplification of the vertical vegetational structure.
Juliani	2010	Bats	-	-	-	Yes	Almost all species that were found in the oil palm plantation can be classified as common species in disturbed areas.	na
Sheldon et al. [37]	2010	Birds	-	-	-	Yes	Most species in oil palm plantation were open country and scrub species that are common throughout Borneo.	Simple botanical structure.

*The causes marked bold were statistically significant.

Table 5 Summary of information on species composition between logged peat forest and smallholder plantations*

Author	Year published	Taxonomic group	Similarity between logged peat forest and plantation	Similarity between logged peat forest and smallholdings	Statistics used	Changes in communities between forest and plantation	Notes on similarity	Causes
Azhar et al. [26]	2011	Birds	21.40%	19.10%	Analysis of similarity, Similarity percentage procedure	Yes	Oil palm management regimes had a similar species composition but both differed from the forest. The bird community in oil palm consisted of non-forest resident, forest-dependent, migratory, and wetland species.	**Extensive canopy cover which in turn may suppress ground layer vegetation that can provide refuge from predators and provide food sources.**

*The causes marked bold were statistically significant.

Table 6 Total species richness in forests and plantations, the number of shared species, and the proportion of species remaining

Authors	Year published	Taxonomic group	Forest species	Plantation species	Number of shared species	Proportion of species remaining
Invertebrates						
Brühl	2001	Ground-dwelling ants	31	23	14	0.45
Chang et al. [27]	1997	Mosquitoes	6	6	6	1.00
Chey [31]	2006	Moths	75	85	28	0.37
Chey [31]	2006	Moths	133	73	28	0.21
Chey [31]	2006	Moths	78	90	11	0.14
Davis & Philips [22]	2005	Dung beetles	25	20	8	0.32
Fayle et al. [42]	2010	Ants (canopy)	120	58	17	0.14
Fayle et al. [42]	2010	Ants (ferns)	36	35	2	0.06
Fayle et al. [42]	2010	Ants (leaf-litter)	216	56	29	0.13
Hashim et al. [41]	2010	Ants	5	7	3	0.60
Hassall et al. [35]	2006	Terrestrial isopods	12	4	0	0.00
Koh & Wilcove [28]	2008	Butterflies	69	15	12	0.17
Room	1975	Ground foraging ants	49	29	11	0.22
Vaessen et al. [33]	2011	Termites	11	6	2	0.18
Mean						0.29
SD						0.26
n						14
95% CI						0.14
Vertebrates						
Aratrakorn et al. [45]	2006	Birds	108	41	21	0.19
Bernard et al. [34]	2009	Non-volant small mammals	6	1	0	0.00
Danielsen & Heegaard	1995	Primates	5	1	0	0.00
Danielsen & Heegaard	1995	Bats	8	1	1	0.13
Fukuda et al. [48]	2009	Bats	19	5	4	0.21
Gillespie et al. [39]	2012	Amphibians	21	12	10	0.48
Glor et al.	2001	Lizards	11	5	4	0.36
Juliani	2010	Bats	9	7	3	0.33
Peh et al.	2005, 2006	Birds	159	40	36	0.23
Azhar et al. [26]	2011	Birds	194	55	49	0.25
Mean						0.22
SD						0.15
n						10
95% CI						0.09

not warrant further exploration, mainly because the cases could not be categorized based on a taxon.

Both temporal and spatial aspects of sampling can create variation in effect sizes, which is why the importance of scale has been emphasized in biodiversity studies [51]. As none of the studies addressed biodiversity changes at landscape level, scale-dependent variation in effect sizes could not be evaluated. Variation in impacts due to seasonality could not be evaluated because the available evidence was based on short term data collection.

The small number of studies did not allow us to conduct quantitative examination of the importance of environmental variables, or variables related to plantation management, such as clearing of ground vegetation or

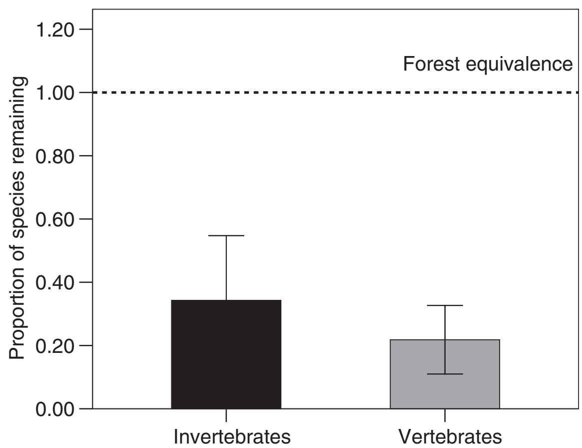

Figure 9 Mean proportion of shared species between oil palm plantation and forest with 95% confidence intervals. Data were standardized by the total number of species recorded in forest (the number of forest species = 1).

type of plantation ownership (smallholdings versus industrial estates). However, there was an indication that both types of variables had some effect [21,26,35,42,43,45] and probably contribute to variation in the effect sizes, as they are most unlikely to be constant from one area to another, or even constant temporally within the same area (for example, because management practices can differ between plantations).

There are also natural processes such as competition and predation that can influence the results and create variation. Competitive interactions were mentioned, though not analysed, in one of the studies [42] but in general the influence of competition and predation were not reported.

Review limitations

This review was based on only one crop, oil palm, with the majority of studies conducted in Malaysia and almost half of the studies in one Malaysian State. We would therefore not want to generalize our findings outside South East Asia.

When biodiversity is compared across natural and human-modified landscapes, there are many factors that can limit the generality of conclusions. Variability is an inherent component of biological systems, and human actions in the studied area as well as in the surrounding landscape can add further variability. One way to account for the variability is to include replication in the study design. Unfortunately, the majority of the studies included in the review included insufficient reporting of study conditions and details, or were poorly replicated or pseudoreplicated, which is common for biodiversity studies [54]. Although it is assumed that site comparison studies pair sites that share common attributes, this is not necessarily the case in practice. For example, only a few studies reported on the type of surrounding landscape or on the original vegetation. A number of unreported factors could therefore have contributed to the true effect sizes.

One significant limitation of the review is the lack of landscape level comparisons. Although comparing production areas with forest provides information of the extent of losses at the management unit level, it does not provide information about whether there is a loss in biodiversity at the landscape level. A landscape level approach would be required to incorporate differences between different landscape mosaics as well as their historical backgrounds, into the analysis.

The 25 papers identified in this review compared oil palm plantations with forest. However for us to understand the differences between management systems and the link between management practices and biodiversity, we also need studies that make further comparisons between differently-managed areas. In this review such stratification was not possible because of the dearth of information. To move beyond comparing forest ecosystem with oil palm plantation, there is a need to conduct a robust impact evaluation of differently-managed areas.

The lack of information also prevented analysis of species or taxa-specific responses which is a limitation of the current review. We combined different taxa in the analyses out of necessity, but can recognized that this can mask responses that are specific to certain groups or taxa. As metrics of biodiversity, species richness and abundance suffer from a similar kind of blindness as they consider all the species and individuals to be equal. The inclusion of community similarity in the review alleviates this limitation to some extent.

Publication bias cannot be wholly discounted, even though there are grounds to assume that it is not a significant problem for this body of literature. Grey and unpublished literature was extensively searched in several languages. Correlations between sample sizes and effects were not significant. Finally, considering the nature of the subject, non-significant findings have the same value as significant ones.

Conclusions

Potential implications for biodiversity conservation, policy, and plantation management

The available evidence suggests that oil palm plantations support lower species richness than primary or secondary forest. Also, forest conversion to oil palm plantation leads to significant changes in community composition, which indicates that oil palm plantations are not suitable habitats for the majority of forest species. Unfortunately, very little information was available about the impacts of smallholder plantations or different standards, which makes it difficult to evaluate their usefulness.

Potential implications for research

The review identified several knowledge gaps about the impacts of biofuel crop cultivation on biodiversity and ecosystem function:

- Landscape level studies that would contribute better knowledge of the impacts at larger scale beyond simple habitat comparisons.
- Research on how reduced species richness or changes in community composition affect ecosystem functions. The lack of knowledge about this topic was also a conclusion of a recent review by Foster *et al.* [53].
- Research on differences in biodiversity and ecosystem function in response to different production systems, (smallholdings vs industrial estates) and different management practices (certified and non-certified plantations).
- Studies on jatropha and soybean and oil palm beyond Malaysia.

To provide a sound evidence base for land-use management decisions, future studies should pay careful attention to study designs, for example by defining the sampling population of land-uses and then using stratified randomization to select study sites, as well as ensuring that seasonality effects are taken into account, and that there are enough replicates. Methodologies should be shared across plantations, users and experiments to identify groups for future monitoring and to make use of crowdsourced identification (e.g. Ispot [55]).

Finally, there are a number of recommendations for authors and publishers that relate to the reporting of biodiversity studies. First, descriptions of methods should be more detailed, including exact explanations for site selection, and descriptions of plantation sizes, ages and management histories. Failure to include such basic information precludes subsequent analysis, and lowers the value of such studies for guiding policy. Second, details of management practices are needed, particularly whether the plantation is certified, and details about which standards are adhered to within the plantation. Finally, crop yields in plantations under different management regimes should be reported to facilitate comparisons that can support policy- and decision-making.

Additional files

Additional file 1: Search terms in different languages.

Additional file 2: Equations used in the quantitative meta-analysis.

Additional file 3: List of studies included in the review.

Additional file 4: Qualitative assessment of standards related to oil palm, jatropha, and soybean.

Competing interests

The authors declare that they have no competing interest.

Author's contributions

SS carried out the literature survey and assessment, extracted data, designed and carried out the statistical analysis. She drafted the systematic review and revised it following reviewers' comments. RN had the idea for the study. SS, MRG, RN, and YL contributed to the design and focus of the study. SS, MG, and MZ assessed the standards. SS, CG, JUG, JG, MG, GP, JS, MZ participated in the workshop where the first draft of the review was discussed and subsequently improved. All authors participated in the revisions of the manuscript. GP and MG edited the language. All authors read and approved the final manuscript.

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